GeoArch

Report 2009/02

Archaeometallurgical residues from Crickhowell Road, Trowbridge, Cardiff

(revised with additional material March 2009)

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30th January 2009

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Abstract

The archaeometallurgical residues from the Roman enclosure at Crickhowell Road, Trowbridge, were almost entirely residues from the working of iron (smithing) in a coal-fired forge. Material from the enclosure ditches mainly comprised macroscopic slags, whereas the material from the internal features was dominantly microscopic residues. The residues were mainly contained in deposits assigned to phase 2c, although deposits of phases 2a, 2b and 2d also produced very small quantities of slag.

Three items were suggestive of iron smelting: a possible smelting slag fragment from C2125, a certain piece of smelting slag from C3296 (Phase 2d) and a piece of iron ore from C3180 (Phase 2d). The ore was probably originally a goethite ore partially altered to haematite by roasting, and resembles ores from the Forest of Dean and South Wales. Its trace element chemistry favours, but does not prove, an origin in the orebodies within the South Crop of the South Wales Coal Basin; the nearest orebodies to the Trowbridge site. These occurrences suggest that iron smelting was undertaken in the vicinity, but probably not within the confines of the excavated area.

Detailed analysis of representative samples of both macro- and micro-residues from the Phase 2c smithing was undertaken. The chemical composition of the residues showed a low silica:alumina ratio and the mineralogy in many instances showed significant development of aluminous spinels This is probably indicative of the influence of the coal ash.

Contents

Methods

All materials were examined visually with a low powered binocular microscope. Macroscopic slag pieces were individually weighed, described and recorded to a database (Table 2). Assemblages of microresidues were given a summary description and weighed in bulk. A provisional summary and interpretation derived from this visual inspection was provided in an evaluation report (Young 2006b).

Samples (Table 1) were chosen for further analysis on the basis of the selection of a closely-associated group of macro- and micro-residues from the Phase 2c smithy. Microresidues were picked by hand from the bulk sample, and then sub-sampled to provide bulk material for chemical analysis in order to achieve the weight of sample required, and a small number of grains for microstructural investigation on the SEM. The use of bulk samples for chemical analysis is not ideal, for it may hide the variability of the particles and also may lead to uncertainty as to whether the subsample imaged on the SEM and that employed for the chemical analysis were both similar to each and representative of the original sample, but at present represents the best approach for analysis.

Chemical analysis was undertaken using two techniques. The major elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, and P) were determined by X-Ray Fluorescence using fused beads, on the Open University Earth Science Department's Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system. Whole-specimen chemical analysis for minor and trace elements was undertaken using samples in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth, Ocean and Planetary Sciences, Cardiff University. Samples for chemical analysis were submitted to the laboratories of the Open University, Earth Science Department, for crushing. They retained powder for X-ray Fluorescence and returned a sub-sample of power for submission for ICP-MS analysis. The bulk chemical analyses are presented in Table 3.

Electron microscopy was undertaken on the LEO S360 analytical electron microscope in the School of Earth, Ocean and Planetary Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX). The archive of microanalysis results are presented in Table 4 with locations given in Plate 6. All petrographic images presented in this report are backscattered electron photomicrographs. The polished blocks for investigation on the SEM were prepared in the Earth Science Department, The Open University.

Results

Iron Ore

Texture: The iron ore (c3180) was a piece derived from a thin stalactitic iron oxide ore seam. The stalactitic zone bears fine-grained oxide stalactites slightly oblique to the overall seam, between rather denser marginal zones. The space between the stalactites is largely occupied by rather coarse botryoidal overgrowth.

The ore fragment was red (indicating it is largely haematite), despite having a texture more normally associated with goethite ores, and had a surface broken by numerous shallow cracks. These observations indicate the ore had been roasted, a usual procedure prior to smelting.

Under the SEM the cracking is shown to be pervasive, particularly in the interstitial areas between the stalactites. The interstitial areas show botryoidal zones as well as regions of fine haematite crossed by polygonal lines of dense haematite suggestive of ghosts of the grain boundaries of precursor carbonate minerals.

Chemical composition: The ore shows a very high iron content with extremely low levels of all other major elements. Silica is extremely low (0.06 wt%).

Trace element compositions are also generally moderate. The trace elements employed by Young (2000) and Young & Thomas (1999) for provenancing ores within the Bristol Channel orefield include V (41.2ppm), Cu (16.6ppm), Zn (133.5ppm), Y (8.7ppm), Ba (18.1ppm), Pb (15.9ppm), Th (0.10ppm) and U (2.66ppm).

Certain distinction between different possible provenances for such ore material is difficult, because of significant overlap between the trace element compositions seen in the various sectors of the orefield. However the bivariate plots (Figure 1) show vanadium and zinc close to or above the limit of compositions observed in the forest of Dean, but well within the range observed in samples from SE Wales. The Trowbridge specimen also plots on or just outside the margins of the Forest of Dean samples on the U v Pb and V v U plots. The Trowbridge material falls outside the range of material observed from the western end of the Vale of Glamorgan and Gower, and also outside the range of specimens from the Mendips.

The total rare earth elements (ΣREE) amount to 32.45ppm. The REE profile (Figure 2) normalised to upper crust (Taylor and MacLennan 1981) shows strong relative enrichment of the middle REE; Gd_N/La_N is 7.92 and Gd_N/Lu_N is 2.18. The strong MREE enrichment appears to be a characteristic of the botryoidally-textured ore, and has been observed in samples from all parts of the orefield (Young 2000).

Provenance: The origin of the piece within the Bristol Channel Orefield cannot be determined with certainty. The sample is extremely unlikely to derive from the Forest of Dean or Worcester Graben sectors on the basis of the moderately high Zn content and unlikely to be from the western parts of the orefield on the basis of the U and Pb contents. The best fit for the trace element chemistry would be from the ore bodies of the South Crop of the South Wales Coal Basin. Most of these orebodies contain a high proportion of quartz-bearing ores, but there are some quartz-free materials, particularly in some of the more botryoidal facies (Gayer & Criddle 1970). Within these orebodies the quartz-free lithologies tend to be the goethitic rather than the haematitic rocks, so the haematite of this specimen may be secondary, induced by dehydration during ore roasting. The REE profile of a botryoidal goethite ore from Llanharry is shown for comparison in Figure 2.

Iron smelting macroresidues

Iron smelting residues were confined to two small fragments of tapped slag. A very small piece of probable tapslag was recovered from C2125 (possibly equal to C3054, Phase 2c) and a larger, certain piece of smelting slag from C3296 (Phase 2d).

Smithing Microresidues

General: Microresidues from pits 3204, 3222, 3225, 3242, 3245, 3275, 3276 all comprise good assemblages of hammerscale. The hammerscale is dominated by rather fine flake hammerscale, but some spheroidal hammerscale is present throughout. Some assemblages show the presence of macroscopic flats, which resemble flake hammerscale but are thicker, and which represent the shedding of thin slag films from the surface of the workpiece or tools.

The ferruginous microresidues were accompanied by residues from the burning of coal and of fine unburnt coal debris.

Fines from C3278 (a possible posthole within the complex of Phase 2c features of the iron working area) were sub-sampled for investigation of the hammerscale. Three fractions were taken: flake hammerscale, spheroidal hammerscale <4mm and spheroidal hammerscale >4mm. For each sample a bulk chemical analysis was made and a selection of particles mounted for examination in polished section under the SEM.

Texture: The flake hammerscale showed a variety of microstructures, often in close proximity. The most common texture was of a roundedly granular wustite (Plate 2f) representing a relict texture from the oxidation of the iron workpiece. This is the classic flake hammerscale texture and is equivalent to microstructure T1 at Coolamurry (Young 2008). A rather more developed neomorphic texture is shown in Plate 2d which is broadly equivalent to texture T2 in the Coolamurry assemblage. The degree of melting indicated by this texture is similar to that seen in the majority of the spheroidal hammerscale. A third microstructure (Plate 2b) is also a recrystallization texture, with the development of both equant and platy magnetite. The magnetite shows cores of up to 24% hercynite, dropping to 8% on the margins. The interstitial phase is fayalite of very close to end-member composition. This texture was not observed at Coolamurry. It shows some similarities with the outer layers of the spheroidal particle shown in Plate 3d. The highly aluminous nature of the spinel suggests the influence of an external aluminous material (fuel ash?) in the development of this scale.

Four particles of spheroidal hammerscale of >4mm (Plate 3) and four spheroidal particles of <4mm (Plate 4), together with one irregular <4mm particle were examined in detail. Most particles had a microstructure dominated by blebby to poorly dendritic wustite (e.g. Plate 3f, Plate 4b, Plate 4f). This microstructure is equivalent to texture S2 at Coolamurry. For one of the <4mm spheroids and the <4mm irregular particle at a part of the material comprised delicately dendritic wustite (Equivalent to Coolamurry texture 3A). For one spheroidal particle <4mm the microstructure was dominated by dendritic magnetite (Plate 4d; equivalent to Coolamurry texture S4). In one of the >4mm particle a marginal zone contained significant magnetite, but the particle was internally finely dendritic wustite.

As with the assemblage from Coolamurry (Young 2008), many of the spheroidal hammerscale particles bear small piece of flake hammerscale in their margins (e.g. Plate 3b and 3h).

The wustite in surficial regions of both flake and spheroidal hammerscale commonly shows a decrease in electron density and this is attributed to partial secondary oxidation of the wustite.

Chemical composition: Both flake and spheroidal hammerscale were dominated by iron oxide, with very low levels of both silica and alumina (2.5-3.8 wt% and 1.9-2.9 wt% respectively). The silica:alumina ratio (by weight) was very low at 1.34 in the flake hammerscale and only reaching 1.45 in the larger fraction of the spheroidal hammerscale. This ratio is interpreted as reflecting the influence of the composition of the coal ash, which is typically aluminous.

Trace elements were typically present in low concentrations. The Upper Crust -normalised REE profile for the three microresidue subsamples are shown in Figure 3. They show a MREE enrichment, with LREE plotting slightly lower than the HREE. The profiles for the microresidues are parallel to that of the smithing hearth cake from Trowbridge (see below), and are also very close to the profiles of equivalent materials from the late Roman coal-fuelled smithy in the basilica at Caerwent (Young 2006a).

Smithing Macroresidues

General: The macroscopic slag assemblage is frequently obscured by ferricrete. In general the material is dominated by rather amorphous slag lumps, but one certain smithing hearth cake (weighing 144g) and two less certain ones (240g and one encrusted in ferricrete at 290g) provide good evidence for smithing. The small size of these SHCs suggests production during blacksmithing, rather than bloom-refining which tends to produce larger SHCs.

Assemblages with a high proportion of amorphous hearth slag lumps are often associated with the use of coal (since the impurities in the coal provide an additional source of silicate material besides the normal source of melting of the blowing wall or tuyère).

Texture: The smithing hearth cake examined (the 292g SHC from C3247) showed an extremely heterogeneous microstructure typical of a smithing slag (Plate 5a,b). The slag shows abundant vesicles, mainly less than 2mm across. The vesicles have curvilinear outlines, but lack the arcuate leucite- rich rims seen in many smithing slags. The primary mineralogy involves a patchy development of wustite, most of which is blebby rather than showing well-developed dendrites, associated with euhedral hercynite (Plate 5c). The hercynite shows 9-14% magnetite and has up to 4% Mg substitution and 1% Ti substitution. The wustite also shows some Al and Ti substitution, typically below 1%.

The primary minerals are followed by fayalite, which in larger crystals shows a zonation from $Fa_{96}Fo_4$ in the cores to $Fa_{98}Fo_2$ on margins. In some areas a late stage generation of smaller laths is seen which is Fa_{100} with up to 1% Ca substitution. The morphology of the olivine is very variable, from some equant crystals of about 1mm, through more common laths of about 1mm, down to late stage small laths. Together with the distribution of wustite, the variation in olivine morphology marks the location of infilled vesicles.

There is little material interstitial to the olivine over much of the specimen, but near some vesicles there is a minor development of leucite and a leucite-wustite cotectite.

Chemical composition: The SHC shows a bulk composition with iron oxide (calculated as FeO) at 63%, Silica at about 21% and alumina at about 8%. All other oxides occur at below 1%.

The silica:alumina ratio is low at 2.6 (by weight), although not as low as in the micro-residues.

The REE show an Upper Crust-normalised profile (Figure 3) that is humped, and parallel to those of the microresidues and to those of similar materials from Caerwent.

Distribution

Macroscopic and microscopic residues both derive from deposits of Phase 2c and they appear to form a coherent group of cogenetic materials.

Most of the macroscopic slag material was derived from the enclosure ditches. This is common feature on early forge sites, where the easily moved slags are dumped away from the forge itself and in the immediate area of the ironworking activity the main finds are of microresidues.

At Trowbridge the microresidues were recovered from a posthole (3202), 11 pits (3204, 3222, 3225, 3227, 3233, 3242, 3245, 3265, 3275, 3276, 3277) and a gully (3289).

Interpretation

Smithing

The assemblage provides remarkably coherent evidence for the smithing of iron using coal. Romano-British smithing employing iron is well-attested in the area, including local examples at Caerwent (Young 2006a) and Bulmore (Young1999). Both the physical nature of the smithing slags and the use of coal at Trowbridge are indicators of blacksmithing rather than bloom-refining; so there is not necessarily any direct link between the evidence for smithing on the site and the very slight evidence for iron smelting.

Although charcoal and coal are very different in their chemical composition, rather little attention has been paid in the archaeometallurgical literature to the differences between the residues from iron working using these two fuels. The chemical differences between the two coals are important, for coal typically contains a much larger inorganic fraction than does charcoal. In charcoal the inorganic component (the ash) is dominated by elements such as calcium (45-65 wt% oxide) and potassium (up to 25% oxide by weight) with low proportions of silica and alumina (together providing <10% of the ash by weight) with a mean silica:alumina ratio of 4.65 for samples in the author's database. In coal ashes the situation is very different, with silica and alumina together comprising 60-80 wt% of the ash, with typical silica:alumina ratios of 1,2 to 2.0 (average of 1.65 for the analyses quoted by Fowler & Gayer 1999 for some South Wales coals). Iron oxide often provides up to 20wt% of a coal ash, which may mean a coal ash is prone to forming clinker rich in iron silicate. Potassium is typically below 2 wt% oxide in coal ash. Calcium is very variable in coal.

The ability of coal fuels to form silicate melts, clinkers, within the body of fuel makes coal a much more "dirty" fuel to use for smithing. The clinker may frequently become attached to the workpiece, since it is being generated pervasively by the fuel in the hot zone. In contrast, charcoal-fuelled smithing hearths do not have significant slag generation within the fuel bed. For traditional clay-lined hearths with simple blowholes or ceramic tuyères the principal silicate input into the hearth will be melting of the technical ceramic where the hot-zone impinges on the clay, typically most markedly immediately above the blowhole. This leads, in such hearths, to the formation of a smithing hearth cake below the blowhole, which receives iron lost from the workpiece and a silicate component from the ceramic of the hearth. This process will be similar whether the hearth is coal- or charcoal-fuelled, but in coal fuelled hearths there is often a great likelihood of developing other slag lumps besides the main cake. In a modern blacksmith's hearth with a cast iron tuyère, there is no longer hot ceramic to act as source of silicate; the fuel ash, slag from the workpiece and any flux must provide any silicate component of the slag generated. Such hearths typically do not form a solid slag cake, but a friable mass of clinker.

This project has provided an opportunity for the examination of both macro- and micro-residues from blacksmithing using coal as a fuel. The investigation of the chemical influences on smithing residues has recently been developed by the author in several reports, most importantly in an in-depth examination of microresidues from the early medieval site at Coolamurry in Ireland (Young 2008) and, closer to the current site, in an examination of late Roman smithing residues from basilica at Caerwent (Young 2006a). Dungworth and Wilkes have recently reported on the origin of hammerscale (Dungworth & Wilkes *in press*), building on the very limited earlier literature (e.g. Unglik 1991).

The smithing hearth cake examined showed a microstructure typical of a smithing slag, with abundant vesicles, a patchy development of wustite and a silicate mineralogy involving both hercynite and fayalite. The silica:alumina ratio is low at 2.6 (by weight), although not as low as in the micro-residues.

The micro-residue show a mineralogy dominated in most cases by wustite (usually with some Al-substitution). The silica:alumina ratio is very low at 1.3 for the flake hammerscale and 1.4 for the spheroidal hammerscale. Some spheroidal particles contained a significant proportion of magnetite, always with a very high level of hercynite substitution.

The rare earth elements show relative enrichment of the middle REE when normalised against Upper Crust (Taylor & McLennan 1981), but the significance of this is uncertain, because similar relative enrichment is characteristic of the coals (Rose 2001), some local clays (potentially used for hearth construction) and local iron ore (and hence potentially the slag inclusions within the iron).

Although the sample size was very small, there are some general points of comparison with the microresidue assemblage from Coolamurry (Young 2008). Firstly both the microstructural observations and the bulk analyses show a much lower silicate component for the microresidues than at Coolamurry. The total of silica and alumina for flake scale was 4.3wt% (Coolamurry: 5-8wt%) and for spheroidal scale was 6.7-7.2wt% (Coolamurry: c.15wt%). The mineralogical implication of this was the microresidue particles examined were all dominated by iron oxides.

There has been rather little work done to examine the chemical controls on hammerscale. Dungworth and Wilkes (in press) have argued that the chemical composition of hammerscale in their experiments was largely controlled by the composition of the slag inclusions in the metal. They demonstrated this through the linear relationship between the contents of manganese and phosphorus in the hammerscale particles and that in the slag inclusions. (Dungworth & Wilkes *in press*, Figure 13). However, this choice of elements is perhaps unfortunate, for both elements are below detection in their clinker sample (Dungworth & Wilkes *in press*, Table 9), so would not be particularly sensitive to the influence of the fuel ash. It is apparent from their data that the silica:alumina ratio of the hammerscale is not the same as that of the slag inclusions. Their Table 9 shows a silica:alumina ratio (by weight) of 6.0 in the slag inclusions of the wrought iron, falling to 3.5 in the spheroidal hammerscale and to 2.5 in the flake hammerscale, very close to the ratio of 2.4 in the clinker. Clearly modification of the silicate component has taken place, though whether through mixing or fractionation is not apparent.

Young (2008) argued that in the assemblage from Coolamurry there was a more aluminous silicate fraction in most particles, possibly from the hearth ceramics, and a more siliceous component present in the smaller spheroids that might have been derived from the use of a sand welding flux. The Coolamurry assemblage including slag flats (silicate-rich sheets with a flake-like morphology) which contained sand grains, suggesting the adherence of a slag which had a composition that suggested the influence of melted ceramic or flux. The sand grains cannot have had an origin in the slag inclusions of the metal. The Coolamurry heaths would have been blown through ceramic tuyères, which would have provided a source of silicate melt into the hearth not present in the experiments of Dungworth and Wilkes (they used a modern hearth with a ferrous tuyère.

Dungworth & Wilkes (in press) provided compelling photographic evidence for the formation of spheroidal hammerscale by expulsion of liquid slag from the weld line during forge welding. The question remaining to be answered is how was that slag generated? Was it influenced solely by the expulsion of molten slag inclusions, or are there surface films of melt, due to the use of a flux or because of silicate melts present in the hearth (from fuel ash and/or from the hearth ceramic)?

In conclusion, the low silica:alumina ratio for the hammerscale at Trowbridge could be taken as the influence of the relatively aluminous coal ash, supporting a model where the influence of external silicate materials assists in the generation of the hammerscale. Alternatively, it is possible that the aluminous composition represent fractionation of internal slag inclusions during partial melting, with expulsion of the partial melt. It is to be hoped that this study provides a useful contribution towards the understanding of the various potential controls.

The low silica:alumina ratio of the smithing hearth cake does reflect the influence of the coal ash, albeit mixed with a major influence from the melted hearth ceramic. Compared with charcoal fuelled smithing slags the mineralogy shows a distinctive development of hercynite, a very low proportion of leucite and calcium substitution in the olivine restricted to less than 1%.

Iron Smelting

The single piece of roasted ore from Phase 2d , a possible tiny piece of iron smelting slag from Phase 2c? and more substantial fragment from Phase 2d provide slight lines of evidence for iron smelting in the general area, but there was no evidence that this was undertaken within the excavated site.

The iron ore has a texture common in iron ores from the Forest of Dean and rather less common in the Glamorgan sector of the Bristol Channel Orefield. If indeed the ore is from the Forest of Dean it would be the farthest west occurrence of Dean ore recognised from the Romano-British period. Evidence to date suggests that the extensive Roman iron smelting in Cardiff employed Glamorgan ores (Thomas 2000). Although not completely certain, the provenancing evidence discussed above makes it extremely likely that ore fragment from Trowbridge is from one of the Glamorgan orebodies.

In the higher parts of the Severn Vale a picture of widespread smelting of iron ore in the low-lying areas has become well-established (Allen 1988; Allen & Fulford 1987, 1990a, 1990b, 1992; Fulford & Allen 1992)., presumably developing to exploit charcoal production from woodlands on low-lying land poor for agriculture. No lying major campaigns of analysis have been undertaken in this area, but what has been done has confirmed a Forest of Dean origin for the ores (Thomas 2000). In the equivalent coastal areas of South Wales Roman iron-making has been suggested in a few places including Rumney Great Wharf (Fulford, Allen & Rippon 1994) and Ely Roman Villa (Storie 1894, Ward 1917, Wheeler 1922); neither yet properly investigated, besides the major iron-smelting undertaken in the area adjacent to the Roman Fort in Cardiff (Webster 1982).

It has been demonstrated that the Cardiff smelting centre was employing ores from the Taff Valley area (probably from the Lesser Garth; Thomas 2000). In comparison to the hinterland of the Forest of Dean, there has been little evidence to date for a dispersed rural smelting industry in South Wales. Much of the ore from the western part of the orefield appears to have been smelted at Caergwanaf (Young 2004) and Cardiff appears to have been the major smelting centre further east, with both centres possibly under some form of state control.

The ore find from Trowbridge is significant, for the tentative Glamorgan provenance suggests that some ore from these sources was being taken to the rural coastal area for smelting. Further work to determine the extent of this activity is clearly desirable.

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Plate Captions

Plate 1. Backscattered electron photomicrographs of iron ore fragment from C3180.

a. Botryoidal facies overgrowth (banded appearance) on stalactitic cores (bright). Scale bar 200 µm.
b. Radially oriented plates of haematite within a highly dehydrated and cracked fine matrix. Scale bar 200µm.
c. Parallel-aligned haematite plates within a fine matrix, bounded by dense haematite boundaries. This texture is probably pseudomorphic after a sparry carbonate. It is cut towards the upper right by a subtle curved zonation, probably the remnants of a botryoidal overgrowth. Scale bar 200µm.
d. Lower magnification showing location of area imaged in (c) as a box. Scale bar 1mm.
e. Variations in density of haematite reflecting the cross sections of stalactites (bright) set in a fine haematitic matrix. Scale bar 1mm.
f. Complex botryoidal texture with a variety of haematite morphology. Scale bar 1mm.

Plate 2. Backscattered electron photomicrographs of flake hammerscale from C3278. All the illustrated pieces are sectioned parallel to the face of the flake.

a. Granular textured flake. Scale bar 1mm.
b. Detail of area shown in (a). Pale grains are magnetite, with darker cores showing up to 24% substitution of hercynite, bright margins have only 8% hercynite substitution. Mid grey grains are of olivine, very close to end member fayalite. Scale bar 100µm.
c. Flake formed of crudely dendritic wustite (this is a neomorphic texture; wustite grown from liquid) with large pores. Scale bar 1mm
d. Detail of area shown in (c). Scale bar 300µm.
e. Flake formed of angular wustite grains. Scale bar 1mm.
f. Detail of area shown in (e) with grain boundaries becoming progressively opened towards the lower right (this is a relict texture; wustite as transformation of metallic iron). Scale bar 200µm.

Plate 3. Backscattered electron photomicrographs of larger spheroidal hammerscale from C3278.

a. Hollow spheroidal hammerscale particles, with flake scale incorporated in margin on right side. Scale bar 2mm.
b. Detail of grain shown in (a), showing the contact between the flake hammerscale particle (150µm thick) and the wustite/fayalite of the once molten spheroidal droplet. Scale bar 200µm.
c. Irregularly shaped sub-spheroidal vesicular particle. Dense oxide crust visible along left side, and apparently fractured into the particle on the lower right. Interior of the grain comprises delicate wustite dendrites in glass, Scale bar 3mm.
d. Detail of grain shown in (c) showing broken wustite crust on lower right. Outer crust (Al-rich wustite?) shows inwardly growing equant grains and platelets of a spinel (52-66% magnetite, 48-34% hercynite). Scale bar 200µm.
e.. Vesicular spheroidal hammerscale particle with large central cavity. Scale bar3mm.
f. Detail of particle shown in (e), showing coarse blebby wustite dendrites with glassy matrix. Scale bar 200µm.
g. Asymmetrical spheroidal hammerscale. Straight margin on left is formed by a flake hammerscale fragment. Scale bar 3mm.
h. Detail of particle shown in (g) with dense wustite of flake particle (120µm thick) in contact with columnar wustite to right and the internal blebby wustite. Scale bar 300µm.

Plate 4. Backscattered electron photomicrographs of smaller spheroidal hammerscale from C3278.

a. Vesicular spheroidal hammerscale particle. Scale bar 2mm.

b. Detail of particle shown in (a), showing rounded wustite blebby dendrites with interstitial glass. Scale bar 90µm.

c. Partially collapsed hollow spheroidal hammerscale particle. Scale bar 1mm.

d. Detail of right side of particle shown in (c), showing granular magnetite crust, supporting magnetite dendrites (pale grey), locally showing some overgrowth by wustite dendrites (white), with interstitial glass (mid grey). Scale bar 100µm.

e. Vesicular spheroidal hammerscale particle. Scale bar 2mm.

f. Detail from upper part of the particle shown in (e), showing variable wustite textures, with coarse blebby wustite dendrites forming most of shell, but finer wustite dendrites occur as filling in early vesicles. Scale bar 200µm.

g. Fragile hollow spheroidal hammerscale particle. Scale bar 1mm.

h. Detail from upper part of particle shown in (g), showing thin wustite crust and contrasting granular wustite body of shell. Scale bar 300µm.

Plate 5. Backscattered electron photomicrographs of smithing hearth cake fragment from C3247

a. Montage showing general structure of the slag. Scale bar 5mm
b. Detail showing heterogeneous texture. Black = void, mid grey = hercynite, pale grey = fayalite, white = wustite. Scale bar 1mm.
c. Detail showing the relationship between wustite (white), fayalite (pale grey) and hercynite (mid grey). Scale bar 100µm

Plate 6. Locations of EDS microanalyses.

a. CHT1 area 11
b. CHT1 area 12
c. CHT1 area 13
d. CHT3 area 3
e. CHT3 area 5
f. CHT3 area 7
g. CHT3 area 9
h. CHT4 area 17
i. CHT5 area 3
j. CHT5 area 5
k. CHT5 area 6
l. CHT5 area 9
m. CHT5 area 13

Figure Captions

Figure 1. Binary scatter plots for selected trace elements showing their concentrations in the ore sample from Trowbridge (CHT2), in comparison with samples from various parts of the Bristol Channel Orefield.

Figure 2. REE profile, normalised against Upper Crust (Taylor & McLennan 1981), for the ore sample from Trowbridge (CHT2) and of a comparative sample of botryoidal goethite ore from Llanharry.

Figure 3. REE profile, normalised against Upper Crust (Taylor & McLennan 1981), for archaeometallurgical residues from Trowbridge, also showing data from comparative samples from the approximately contemporary, and technological similar, smithy from Caerwent (Young 2006a).

Sample	*Context*	*Sample*	*Phase*	*Description*
CHT1	3247	14	2c	Smithing hearth cake (SHC)
CHT2	3180		2d	Roasted ore fragment
CHT3	3278	23	2c	Flake hammerscale
CHT4	3278	23	2c	Spheroidal particles >3mm
CHT5	3278	23	2c	Spheroidal particles <3m

Table 1. Sample details

context	***sample***	***label***	***weight***	***description***	***context notes***	***phase***
1704			134	Two pieces of vesicular smithing slag. Larger piece (117g) shows coal residue in vesicles and shale fragments	=2nd or 3rd fill fo ditch 3101	2c
1706			10	Weathered vesicular glassy slag with purple surface, has adhering particle of coal	=3336 fill of ditch 3335	2a
2105	3	slag	0.5	mainly coal and burnt coal residue	not known	?
2107	4	slag	9	rusty iron pan material with tubular concretion	not known	?
2113		slag	46	2 dimpled blebs of slag - no fuel inclusions	not known	?
2125		slag	38	dense well flowed lobate slag, worn, could be a smelting slag	not known	?
2126	5	slag	0.5	mainly coal and burnt coal residue, some ?charcoal	not known	?
2127	6	choke		burnt stone, clinker, slag	not known	?
3030	1	magnetic material	<	tiny scraps of ?flake	2nd fill of ditch 3028	2b
3033		slag	150	1 large slag lump, 3 small, 1 piece of ferricrete. Largest, 118g, is irregular broken piece, but has one smooth blown surface suggesting top of SHC, with angled lower part suggesting it was moderately sized	2nd fill of ditch 3031	2c
3033	2	fired clay	96	14 pieces of granular ferricrete poor in archaeometallurgical residues	2nd fill of ditch 3031	2c
3033	2	magnetic material	<	burnt stone and 1 flake	2nd fill of ditch 3031	2c
3053		slag	82	dense slag rich in shale fragments, in 3 pieces	5th fill of ditch 3052	2a
3054		slag	76	3 pieces of fired lining and 7 pieces of lining slag including fused gravelly material	fill of ditch 3063	2c
3054		slag	44	lining- or shale-rich slag nub	fill of ditch 3063	2c
3082		slag	6	dimpled slag with coke in ferricrete	3rd fill of ditch 3052	2a
3088		slag	22	dimpled slag with coke in ferricrete	fill of ditch 3087	2a
3126		slag	440	amorphous block of very charcoal-rich slag, porous	fill of ditch 3125	2c
3146		slag	1.39	reduced-fired vitrified clay with strongly curved surface	Fill of ditch 3145	2a
3171		slag	232	small dense irregular SHC	fill of ditch 3233	2c
3171		slag	1	shale-rich clinker	fill of ditch 3233	2c
3180		slag	130	rounded lump of reddish goethite iron ore broken into 4. Shows internal evidence for short stalactitic zone in centre with gaps between stalactite filled by botryoidal material, surface shows cracking and is slightly magnetic - so has been roasted	fill of ditch 3179	2d
3186		slag	204	2 pieces of slag, larger (144g) is small SHC with burr area and accretion	2nd fill of ditch 3184	2d
3203	5	hammerscale	1004	very rich smithing fines assemblage - flake, spheres, flats, slag	fill of posthole 3202?	2c
3203	5	slag	38	many small pieces, some slag but mainly coal	fill of posthole 3202?	2c
3205	6	metal residue	17	good hammerscale assemblage	Fill of pit 3204	2c
3223	9	magnetic material		rusty material	Fill of pit 3222	2c
3226	7	magnetic material	7	good hammerscale assemblage	Fill of pit 3225	2c
3226	7	hammerscale	0.5	big flake hammerscale pieces and large spheroids	Fill of pit 3225	2c
3228	8	fired clay	234	35 -pieces of gravelly ferricrete	fill of pit 3227	2c
3228	8	magnetic material	6	good hammerscale assemblage	fill of pit 3227	2c
3230	12	hammerscale	1	big flake hammerscale pieces and large spheroids	Fill of pit 3222	2c
3230	12	magnetic material	4	good hammerscale assemblage	Fill of pit 3222	2c
3231	22	fired clay	348	25 pieces of gravelly ferricrete	fill of pit 3265	2c
3231	22	magnetic material	<	small hammerscale assemblage	Fill of pit 3265	2c

context	***sample***	***label***	***weight***	***description***	***context notes***	***phase***
3236	10	hammerscale 0.5 - 11.2 mm	204	mainly slag and coal debris, but some coarse flake hammerscale and slag	fill of posthole 3202	2c
3241	13	fired clay	28	45 small ferricrete pieces	fill of pit 3225	2c
3241	13	magnetic material	2	good hammerscale assemblage	fill of pit 3225	2c
3244	15	fired clay	416	c30 pieces of smithing pan. Only 1 tiny certain piece of slag	2nd fill of pit 3242	2c
3244	15	magnetic material	14	good hammerscale assemblage	2nd fill of pit 3242	2c
3247	14	fired clay	1625	c40 pieces of slag and 4 pieces of lining in ferricrete. 290g and 252g two largest pieces. All smithing slag debris probably, with 290g piece roughly plano-convex. Ferricrete rich in hammerscale	first fill of pit 3245	2c
3247	14	slag	54	26 slag pieces, mainly broken debris but also 2 irregular large spheroids	first fill of pit 3245	2c
3247	14	magnetic material	23	good hammerscale assemblage	first fill of pit 3245	2c
3251	16	fired clay	206	c 60 pieces of gravelly ferricrete	fill of pit 3228	2c
3251	16	magnetic material	1	good hammerscale assemblage	fill of pit 3228	2c
3256	17	fired clay	626	39 pieces of ferricrete mainly cored on slag, 1 lining fragment	2nd fill of pit 3245	2c
3256	17	slag/coal 1-2mm	47	coal and fired clay mainly - some slag including spheroidal scale	2nd fill of pit 3245	2c
3256	17	magnetic material	22	good hammerscale assemblage	2nd fill of pit 3245	2c
3256	17	hammerscale	0.5	slag charcoal spheroids	2nd fill of pit 3245	2c
3256	17	slag	72	many tiny pieces of slag, coal and ferricrete fines (also burnt bone and stone)	2nd fill of pit 3245	2c
3259	19	fired clay	52	24 small ferricrete fragments and 4 small pieces of slag	fill of pit 3276	2c
3259	19	magnetic material	9	good hammerscale assemblage	fill of pit 3276	2c
3260	18	fired clay	204	c 60 pieces of gravelly ferricrete	1st fill of pit 3245	2c
3260	18	magnetic material	5	good hammerscale assemblage	1st fill of pit 3245	2c
3264	21	slag	12	7 small slag pieces, largest has coke	fill of pit 3275	2c
3264	21	fired clay	8	12 small ferricrete pieces	fill of pit 3275	2c
3264	21	magnetic material	12	good hammerscale assemblage	fill of pit 3275	2c
3266	24	magnetic material	21	good hammerscale assemblage	2nd fill of pit 3242	2c
3268	26	fired clay	518	c 50 pieces of smithing pan, 2 pieces of ferricrete on slag and 2 pieces of ferricrete on corroded iron	fill of pit 3275	2c
3268	26	slag	10	8 small slag fragments and 11 sub-spheroidal drips	fill of pit 3275	2c
3268	26	magnetic material	25	good hammerscale assemblage	fill of pit 3275	2c
3278	23	hammerscale	870	v rich smithing fines assemblage - flake, spheres, flats, slag	fill of pit 3277	2c
3278	23	slag	0.5	coal and slag fines	fill of pit 3277	2c
3290		slag	460	4 pieces of slag, some dense, particularly the largest a 240g somewhat pillulous amorphous irregular nub	fill of gully 3289	2c
3296		slag	31	Small fragment of a flow of tap slag. A good, dense flow with central cavity.	Fill of pit 3295	2d

Table 2. Summary catalogue of archaeometallurgical residues structured by bag

	SiO_2	**Al_2O_3**	**Fe_2O_3**	***FeO***	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**	**LOI** 100% FeIII	***LOI*** *100% FeII*	**total**	**S**
CHT1: SHC	20.59	7.79	70.00	*63.00*	0.099	0.32	0.31	0.27	0.42	0.324	0.823	-1.41	*5.59*	99.53	0.16
CHT2: roasted ore	0.06	0.15	97.65	*87.88*	0.044	0.25	0.05	0.10	0.02	0.010	0.094	0.34	*10.10*	98.77	0.01
CHT3: flake h/s	2.49	1.86	98.24	*88.41*	0.052	0.05	0.09	0.18	0.11	0.086	0.498	-5.27	*4.55*	98.38	0.06
CHT4: spheroids >3mm	4.24	2.93	96.47	*86.82*	0.033	0.10	0.11	0.18	0.16	0.124	0.614	-6.45	*3.20*	98.51	0.09
CHT5: spheroids <3mm	3.80	2.64	97.18	*87.47*	0.036	0.08	0.11	0.19	0.12	0.114	0.623	-5.62	*4.10*	99.28	0.08

Table 3a: Major elements analyses by XRF. Analyses shown calculated on the basis of all iron as FeIII with measured loss on ignition (LOI). Alternative values with iron recalculated on the basis of all iron as FeII and with calculated LOI are given in shaded boxes. A negative loss on ignition is a gain on ignition. All values in weight%.

	Sc	**V**	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Sn**	**Cs**	**Ba**
CHT1: SHC	13.8	63.3	41.5	14.6	16.1	34.8	86.3	7.5	20.3	598.7	31.8	92.2	5.72	14.37	0.50	1.78	580.7
CHT2: roasted ore	1.0	41.2	10.7	6.2	30.6	16.6	133.5	3.0	0.7	9.5	8.7	4.5	0.12	13.54	0.98	0.06	18.1
CHT3: flake h/s	3.1	16.3	2.7	16.0	42.9	42.7	145.9	5.1	3.9	114.2	5.8	21.9	1.26	21.27	0.35	0.24	109.0
CHT4: spheroids >3mm	2.9	29.3	21.9	14.2	43.5	33.2	52.2	5.9	5.6	364.3	10.9	33.1	2.13	23.95	0.53	0.35	237.3
CHT5: spheroids <3mm	1.8	27.8	10.6	13.7	33.5	25.7	41.1	5.7	4.7	206.9	8.5	30.3	1.84	25.12	1.12	0.29	166.9

Table 3b: Selected trace elements analysed by ICP-MS. All values in parts per million (ppm).

	La	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Hf**	**Ta**	**Pb**	**Th**	**U**
CHT1: SHC	28.59	60.56	7.65	29.43	7.19	1.68	7.22	1.08	5.64	0.93	2.58	0.37	2.21	0.33	2.23	0.25	2.11	5.82	1.94
CHT2: roasted ore	2.88	9.82	1.26	6.04	3.03	0.78	2.89	0.53	2.76	0.41	1.04	0.14	0.79	0.11	0.08	0.01	15.94	0.10	2.66
CHT3: flake h/s	5.13	11.17	1.29	4.88	1.15	0.26	1.16	0.18	0.98	0.17	0.47	0.07	0.45	0.07	0.53	0.09	3.04	1.14	0.46
CHT4: spheroids >3mm	9.70	20.34	2.47	9.42	2.27	0.53	2.34	0.36	1.88	0.32	0.90	0.13	0.79	0.12	0.83	0.15	1.46	2.04	0.68
CHT5: spheroids <3mm	7.36	15.80	1.89	7.26	1.75	0.39	1.75	0.27	1.48	0.25	0.71	0.10	0.63	0.10	0.75	0.13	1.98	1.74	0.64

Table 3c: Selected trace elements analysed by ICP-MS. All values in parts per million (ppm).

Sample	Area	Spectrum	Processing option	Phase	Weight%														
					Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Fe	As	Ba	O	Total
CHT1	11	1	O by stoichiometry	olivine	0.00	0.41	0.16	14.12	0.13	0.00	0.00	0.00	0.00		53.69		0.00	32.05	100.56
CHT1	11	2	O by stoichiometry	olivine	0.00	0.51	0.20	14.07	0.11	0.00	0.00	0.00	0.00		52.96		0.00	31.86	99.71
CHT1	11	3	O by stoichiometry	olivine	0.00	0.65	0.15	14.10	0.00	0.00	0.00	0.14	0.00		53.24		0.00	31.93	100.21
CHT1	11	4	O by stoichiometry	olivine	0.00	0.00	0.29	13.52	0.32	0.00	0.00	0.17	0.00		53.68		0.00	31.51	99.47
CHT1	11	5	O by stoichiometry	olivine	0.00	0.00	0.20	13.89	0.16	0.00	0.00	0.15	0.00		53.67		0.00	31.65	99.72
CHT1	11	6	O by stoichiometry	olivine	0.00	0.53	0.00	13.99	0.00	0.00	0.00	0.00	0.00		52.82		0.00	31.42	98.76
CHT1	11	7	O by stoichiometry	olivine	0.00	0.00	0.16	14.00	0.11	0.00	0.00	0.22	0.00		53.58		0.00	31.68	99.76
CHT1	11	8	O by stoichiometry	olivine	0.00	0.36	0.19	13.84	0.00	0.00	0.00	0.08	0.00		53.04		0.00	31.40	98.92
CHT1	11	9	O by stoichiometry	olivine	0.00	0.16	0.21	13.73	0.21	0.00	0.00	0.00	0.00		53.43		0.00	31.52	99.26
CHT1	11	10	O by stoichiometry	hercynite	0.00	0.00	25.28	0.37	0.00	0.00	0.00	0.00	0.92		39.17		0.00	34.74	100.49
CHT1	11	11	O by stoichiometry	hercynite	0.00	0.00	25.43	0.31	0.00	0.00	0.00	0.00	0.84		38.76		0.00	34.64	99.98
CHT1	11	12	O by stoichiometry	glass	3.01	0.00	9.37	17.53	1.75	0.56	5.81	3.08	0.00		16.46		1.14	39.72	98.42
CHT1	11	13	O by stoichiometry	glass	2.99	0.00	10.44	18.86	1.33	0.30	6.63	2.43	0.00		14.39		1.05	40.55	98.97
CHT1	11	14	O by stoichiometry	leucite?	0.88	0.00	12.31	25.24	0.00	0.00	14.54	0.13	0.00		4.30		0.47	44.32	102.19
CHT1	11	15	O by stoichiometry	hercynite	0.00	0.00	25.35	0.34	0.00	0.00	0.00	0.00	0.69		39.12		0.00	34.60	100.10
CHT1	11	16	O by stoichiometry	olivine	0.00	0.00	0.47	11.95	0.41	0.00	0.00	0.28	0.00		52.49		0.00	29.72	95.34
CHT1	11	17	O by stoichiometry	glass	0.58	0.00	23.40	4.39	0.61	1.74	1.15	0.54	0.99		36.74		0.00	41.04	111.17
CHT1	11	18	O by stoichiometry	glass	0.99	0.00	3.50	14.42	0.71	0.00	1.27	0.68	0.14		46.60		0.00	34.77	103.08
CHT1	11	19	O by stoichiometry	glass	2.90	0.00	10.57	17.45	1.43	0.54	5.53	2.24	0.00		18.71		1.19	40.47	101.04
CHT1	11	20	O by stoichiometry	olivine mixture	0.00	0.00	3.72	12.17	0.22	0.00	0.09	0.19	0.20		51.77		0.00	32.51	100.86
CHT1	12	1	O by stoichiometry	hercynite	0.56		27.22	0.12	0.00				0.16		35.72	0.00		35.06	98.85
CHT1	12	2	O by stoichiometry	hercynite	0.49		27.30	0.10	0.00				0.17		36.68	0.00		35.33	100.07
CHT1	12	3	O by stoichiometry	hercynite	0.50		27.06	0.16	0.00				0.13		36.40	0.00		35.09	99.33
CHT1	12	4	O by stoichiometry	hercynite	0.26		26.07	0.28	0.00				0.38		37.77	0.00		34.75	99.50
CHT1	12	5	O by stoichiometry	hercynite	0.46		25.76	0.10	0.00				0.12		38.26	0.50		34.53	99.74
CHT1	12	6	O by stoichiometry	wustite	0.00		0.52	0.20	0.00				0.43		72.66	0.00		21.81	95.63
CHT1	12	7	O by stoichiometry	wustite	0.00		0.48	0.18	0.00				0.30		72.74	0.00		21.66	95.36
CHT1	12	8	O by stoichiometry	olivine	0.59		0.33	13.67	0.00				0.00		52.89	0.00		31.42	98.91
CHT1	12	9	O by stoichiometry	olivine	0.41		0.26	13.77	0.19				0.00		52.82	0.00		31.56	99.00
CHT1	12	10	O by stoichiometry	olivine	0.37		0.35	13.78	0.12				0.00		53.09	0.00		31.62	99.33
CHT1	13	1	O by stoichiometry	hercynite		0.67	27.25	0.15	0.00	0.00		0.00	0.19	0.16	36.10			35.45	99.98
CHT1	13	2	O by stoichiometry	hercynite		0.12	26.33	0.30	0.10	0.00		0.00	0.49	0.00	38.47			35.32	101.13
CHT1	13	3	O by stoichiometry	outer crust		0.00	0.70	1.19	0.63	0.18		0.21	0.00	0.00	49.01			17.20	69.13

Sample	Area	Spectrum	Processing option	Phase	Weight%														
					Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Fe	As	Ba	O	Total
CHT1	13	4	O by stoichiometry	inner crust		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	67.38			19.30	86.68
CHT1	13	5	O by stoichiometry	olivine		0.75	0.14	13.77	0.00	0.00		0.10	0.00	0.00	52.68			31.43	98.86
CHT1	13	6	O by stoichiometry	olivine		0.87	0.15	13.79	0.22	0.00		0.00	0.00	0.00	51.99			31.59	98.61
CHT1	13	7	O by stoichiometry	olivine		0.38	0.21	13.65	0.21	0.00		0.11	0.00	0.00	52.85			31.44	98.85
CHT1	13	8	O by stoichiometry	hercynite		0.47	26.84	0.13	0.10	0.00		0.00	0.20	0.00	36.54			35.07	99.35
CHT1	13	9	O by stoichiometry	olivine		0.00	0.66	13.82	0.59	0.00		0.31	0.00	0.00	52.58			32.27	100.23
CHT1	13	10	O by stoichiometry	olivine		0.00	0.36	13.39	0.23	0.00		0.18	0.00	0.00	52.49			30.99	97.64
CHT1	13	11	O by stoichiometry	olivine		0.00	1.97	11.21	0.57	0.00		0.32	0.00	0.00	49.48			29.56	93.12
CHT1	13	12	O by stoichiometry	?		0.00	0.49	1.26	0.94	0.08		0.17	0.00	0.00	50.03			17.61	70.59
CHT1	13	13	O by stoichiometry	?		0.00	1.34	1.63	0.73	16.57		0.21	0.00	0.00	57.17			45.27	122.93
CHT3	3	1	All analysed	magnetite															
CHT3	3	2	All analysed	magnetite															
CHT3	3	3	All analysed	magnetite															
CHT3	3	4	All analysed	magnetite															
CHT3	3	5	All analysed	magnetite															
CHT3	3	6	All analysed	magnetite															
CHT3	3	7	All analysed	olivine															
CHT3	3	8	All analysed	olivine															
CHT3	3	9	All analysed	magnetite															
CHT3	3	10	All analysed	magnetite															
CHT3	5	1	All analysed	wustite			0.56	0.51							73.06			25.25	99.38
CHT3	5	2	All analysed	wustite			0.54	0.00							73.83			24.77	99.15
CHT3	5	3	All analysed	wustite			0.46	0.19							73.95			25.33	99.93
CHT3	5	4	All analysed	wustite			0.46	0.17							73.84			25.03	99.49
CHT3	5	5	All analysed	wustite			0.59	0.00							72.85			25.06	98.50
CHT3	7	1	All analysed	wustite			0.17	0.00	0.00		0.00				65.42			23.54	89.13
CHT3	7	2	All analysed	wustite			0.00	0.00	0.00		0.00				73.17			27.31	100.48
CHT3	7	3	All analysed	wustite			0.00	0.00	0.00		0.00				67.51			24.35	91.86
CHT3	7	4	All analysed	mixed			1.53	3.13	0.13		0.19				58.27			26.15	89.40
CHT3	7	5	All analysed				0.00	0.00	0.00		0.00				69.90			27.08	96.98
CHT3	9	1	All analysed	wustite			0.21								74.40			24.48	99.09
CHT3	9	2	All analysed	wustite			0.32								73.86			24.42	98.59
CHT3	9	3	All analysed	wustite			0.41								73.58			24.51	98.49
CHT3	9	4	All analysed	wustite			0.47								73.39			26.40	100.27

Sample	Area	Spectrum	Processing option	Phase	Weight%														
					Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Fe	As	Ba	O	Total
CHT4	17	1	All analysed	wustite	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00		70.85			25.01	96.28
CHT4	17	2	All analysed	wustite	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00		70.51			24.32	95.25
CHT4	17	3	All analysed	glass	0.49	0.00	4.11	10.78	0.42	0.71	0.72	0.38	0.00		48.06			32.44	98.10
CHT4	17	4	All analysed	glass	0.60	0.16	3.49	13.69	0.49	0.94	1.07	0.50	0.00		41.39			34.91	97.24
CHT4	17	5	All analysed	wustite	0.00	0.00	0.83	0.21	0.00	0.00	0.00	0.00	0.17		69.64			25.22	96.06
CHT4	17	6	All analysed	wustite	0.21	0.00	1.63	1.34	0.00	0.11	0.10	0.11	0.10		65.60			25.92	95.12
CHT4	17	7	All analysed	hercynite	0.00	0.18	11.59	0.44	0.00	0.00	0.00	0.00	0.30		52.38			32.30	97.18
CHT4	17	8	All analysed	hercynite	0.00	0.00	11.55	0.33	0.00	0.00	0.00	0.00	0.31		52.39			32.48	97.05
CHT4	17	9	All analysed	hercynite?	0.00	0.00	7.50	0.68	0.00	0.00	0.00	0.00	0.34		57.63			30.87	97.03
CHT4	17	10	All analysed	outer rim	0.00	0.21	1.23	0.16	0.00	0.00	0.00	0.10	0.00		64.47			29.58	95.76
CHT4	17	11	All analysed	outer rim	0.00	0.16	0.33	0.17	0.00	0.00	0.00	0.00	0.00		66.22			27.75	94.62
CHT4	17	12	All analysed	glass	0.48	0.12	2.42	12.28	0.41	0.61	0.94	0.42	0.00		46.05			33.57	97.29
CHT5	3	1	All analysed	wustite			0.54								73.44			23.55	97.53
CHT5	3	2	All analysed	wustite			0.56								73.54			24.04	98.14
CHT5	3	3	All analysed	wutsite			0.52								73.29			23.63	97.44
CHT5	3	4	All analysed	wustite			0.50								73.86			23.45	97.81
CHT5	5	1	All analysed	wustite			0.60								71.87			24.42	96.89
CHT5	5	2	All analysed	wustite			0.79								71.97			23.98	96.74
CHT5	6	1	All analysed	glass	0.46		5.92	13.89	0.55	0.35	0.84	0.48			42.10			36.05	100.65
CHT5	6	2	All analysed	glass	0.34		5.91	13.81	0.57	0.46	0.62	0.40			39.47			35.35	96.95
CHT5	6	3	All analysed	glass	0.40		6.15	14.42	0.61	0.42	0.74	0.51			39.26			36.61	99.12
CHT5	9	1	All analysed	glass	0.65		2.71	13.11	0.88	1.29	1.13	0.83			41.92			33.96	96.48
CHT5	9	2	All analysed	glass	0.56		2.62	11.36	0.56	0.80	1.08	0.40			45.57			31.23	94.19
CHT5	9	3	All analysed	glass	0.64		2.37	10.56	0.85	0.54	0.82	0.45			49.91			30.64	96.78
CHT5	9	4	All analysed	wustite	0.00		0.42	0.00	0.00	0.00	0.00	0.00			72.03			24.81	97.25
CHT5	9	5	All analysed	wustite	0.00		0.54	0.16	0.00	0.00	0.00	0.00			71.22			24.84	96.77
CHT5	9	6	All analysed	wustite	0.00		0.70	0.17	0.00	0.00	0.00	0.00			70.51			24.74	96.12
CHT5	9	7	All analysed	glass /wustite	0.47		2.29	7.06	0.22	0.23	0.34	0.14			59.91			29.38	100.03
CHT5	9	8	All analysed	glass	0.73		3.53	12.48	0.70	0.58	1.13	0.48			43.01			33.66	96.30
CHT5	9	9	All analysed	wustite	0.00		0.87	0.15	0.00	0.00	0.00	0.00			69.72			25.09	95.83
CHT5	9	10	All analysed	wustute	0.00		0.87	0.00	0.00	0.00	0.00	0.00			70.09			24.53	95.48
CHT5	9	11	All analysed	glass	0.56		3.88	12.63	0.65	1.47	0.43	0.43			44.59			33.63	98.28
CHT5	9	12	All analysed	glass	0.67		4.49	13.17	0.39	0.63	1.58	0.28			42.34			34.44	98.00
CHT5	9	13	All analysed	glass	0.50		4.03	13.21	0.67	1.28	0.83	0.37			44.23			33.60	98.73

Sample	Area	Spectrum	Processing option	Phase	Weight%														
					Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Fe	As	Ba	O	Total
CHT5	13	1	All analysed	magnetite	0.00	0.00	0.70	0.09	0.00	0.00	0.00	0.00	0.00		66.47			27.54	94.80
CHT5	13	2	All analysed	magnetite	0.00	0.20	5.07	0.19	0.00	0.00	0.00	0.00	0.23		61.02			28.97	95.68
CHT5	13	3	All analysed	magnetite	0.00	0.15	4.99	0.37	0.00	0.00	0.00	0.00	0.19		60.91			29.04	95.67
CHT5	13	4	All analysed	magnetite	0.00	0.15	4.65	1.55	0.00	0.00	0.20	0.12	0.13		59.69			29.68	96.16
CHT5	13	5	All analysed	wustite	0.00	0.16	0.94	0.54	0.00	0.00	0.00	0.00	0.00		68.29			24.92	94.83
CHT5	13	6	All analysed	glass	0.58	0.34	2.66	14.81	0.43	0.53	1.03	0.55	0.00		43.23			34.85	99.00
CHT5	13	7	All analysed	glass	0.49	0.24	2.43	15.48	0.44	0.64	1.30	0.59	0.00		41.54			35.56	98.71
CHT5	13	8	All analysed	glass	0.43	0.31	2.43	14.66	0.35	0.47	1.10	0.44	0.00		43.73			34.29	98.20
CHT5	13	9	All analysed	magnetite	0.24	0.00	5.90	0.82	0.00	0.00	0.10	0.00	0.19		59.68			28.95	95.88

Table 4: Microanalyses by EDS. Results in elemental weight%.

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